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Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report results from a contract tasking The Swedish Defense Research Agency as follows: A basic research program will be conducted to calculate stress intensity factor (K) solutions not only for symmetric but also unsymmetric corner cracks at a hole subject to general loading. The p-version finite element method (FEM) with a mathematical splitting scheme will be used to enable efficient and accurate calculations. All structurally significant crack shapes are to be considered. In addition, combinations of crack depth to crack length (a/c), crack depth to sheet thickness (a/t), and hole radius to sheet thickness (r/t) ratios are to be analyzed at each side of the hole; thus more than 106 solutions are to be developed with control of the error in the computed K solutions. The loading conditions will be remote tension, remote bending, and pin loading (bearing). The new K solutions will be implemented in AFGROW.

15. SUBJECT TERMS
EOARD, Materials, Fracture mechanics, Failure Mechanisms, Metallic Materials

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(1) In accordance with Defense Federal Acquisition Regulation 252.227-7036, Declaration of Technical Data Conformity (Jan 1997),

"The Contractor, Swedish Defense Research Agency, hereby delcares that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. F61775-02-WE023 is complete, accurate, and complies with all requirements of the contract.

DATE: 1 March, 2004

Name and Title of Authorized Official: Ingvar Roos

(2) In accordance with the requirements in Federal Aquisition Regulation 52.227-13, Patent Rights—Acquisition by the *U.S.* Government (Jun 1989),

(B) "I certify that there were no subject inventions to declare as defined in FAR 52.227-13, during the performance of this contract."

DATE: 1 March, 2004

Name and Title of Authorized Official: Ingvar Roos

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SUMMARY REPORT

Accurate Stress Intensity Factor Solutions for Unsymmetric Corner Cracks at a Hole Subject to General Loading

EOARD Supported Research

Reference: SPC 024023

Date: Feb 26, 2004

Background

In fatigue design of aircraft structures so called stress intensity factor data (*K*) are needed for cracks of various sizes. One of the most important geometries is small-cracks located at rivet holes in the aircraft skin.

It was recently shown that the few (i.e. of order hundred) existing numerical solutions have errors ranging from 2% up to 40%, which is unacceptably large [1].

The need for accurate *K*-data, and, for a larger parameter range motivated the present research.

In the present work (Ref: SPC 024023) about 5 million new solutions have been derived with a guaranteed relative error below 1%. Novel mathematical/numerical methods were used in the project.

Crack geometries considered

The figure below shows the geometries studied (Note: wedge angle used is 0 degrees and b=t). There are two quarter elliptical cracks at the hole boundary. More detailed technical results from the present project are reported in [2]. For a method description, see [3].

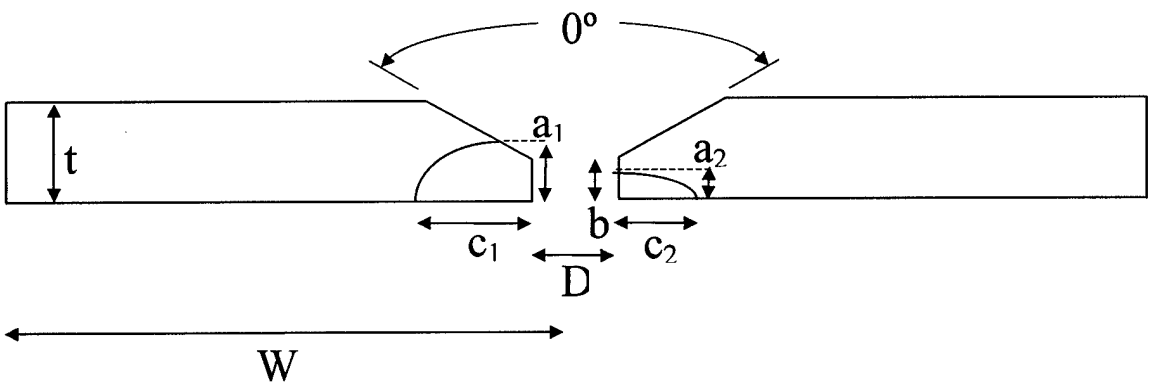

Figure 1 Two Unsymmetric Corner Cracks at a Cylindrical Hole

Hole Geometry
Cylindrical hole with radius R=D/2 (countersunk angle = 0°)
b/t = 1.0

Part-Through Elliptical Crack Sizes

The following parameter sets were analyzed.

a_i/c_i = 0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 0.80, 1.0, 1.25, 1.333, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0

a_i/t = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99

r/t = 0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 1.0, 1.25,1.333, 1.5, 1.666, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0

In the present work, R=2 units and W=200 units were used in the numerical calculations. For other dimensions, all *K*-data scales as the square root of (r/2), where r is the actual radius.

Material data in the plate is isotropic with Poisson's ratio 0.3.

For 25 r/t ratio's, 11 a/t ratio's, 25 different a/c ratio's and three types of loading (tensile, bending and wedge loading), the total number of *K* -solutions, in case of two cracks, is 25*11*25*25*3= 5156250. The number of single crack solutions is 20625. For each of the over 5 million solutions, the mode I, mode II and the mode III stress intensity factors have been computed at 77 points at each crack front (hence, over 2 billion *K*-numbers are stored in the stress intensity factor library).

Stress Intensity Factor Library

All computed *K*-data are today stored on the computer *strato2* at *the* USAF Academy in Colorado Springs, CO.

Summary

The work stipulated in the contract, Order Number F61775-02-WE023, has therefore been completed.

Acknowledgements

A part of all computations (about 40%, corresponding to about 200,000 CPu-hours) was supported by a grant of computer time from the DOD High Performance Computing Modernization Program at ERDC.

Sincerely,

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References:

[1] S Fawaz, B Andersson, "Accurate Stress Intensity Factor Solutions for Unsymmetric Corner Cracks at a Hole". Presented at Fourth Joint DoD/FAA/NASA Conference on Aging Aircraft, May 15-18, 2000, MO US

[2] S Fawaz, B Andersson, and J C Newman Jr, "Experimental Verification of Stress Intensity Factor Solutions for Corner Cracks at a Hole Subject General Loading", International Committee for Aeronautical Fatigue, ICAF 2003, Lucern, Switzerland, May 5-7, 2003

[3] S Fawaz, B Andersson, "Accurate Stress Intensity Factor Solutions for Corner Cracks at a Hole", *Engineering Fracture Mechanics,* Vol. 71/9-10, pp 1235-1254, 2004